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CLIMATOLOGICAL MEMORANDUM No. 34

THE COMPUTATION OF MONTHLY SUMMARIES OF WINDS FROM INCOMPLETE DATA.

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SUMMARY. Results are given of tests carried out to provide statistics on which to base a decision as to which of two methods recommended in the Guide to Climatological Practices for computing mean values for combined hours of observations should be used in the production of routine summaries of upper winds by electronic computer.

INTRODUCTION.

There are three simple methods of computing combined hours values of an element:

(a) to compute a daily mean value for each day from values at different hours and then to take the mean of these values as the combined hours mean value for the month;

(b) to compute a monthly mean for each hour of observation and then take the mean of these as the monthly mean;

(c) to divide the sum of all available values by the number of observations.

If there are complete observations at each hour all three methods will, of course, give the same answer, but if, as is usual with upper air data, there are missing observations (e.g. at high levels), the different methods give different means. Which method may be expected to give the best value on a particular occasion depends on the nature of the distribution and on what values have been lost. For many years the view adopted in the upper air climatological section of the Meteorological Office was that, as it is impracticable in routine work to study each distribution, the use of method (c) i.e. giving equal weight to each observation, is probably the best compromise. The Guide to Climatological Practices (ref.1) recommends the use of either method (a) or (b).

The existing computer programme has been drawn up using method (c) to compute wind summaries for combined hours. A subsequent modification made to the programme, in view of the recommendations in the Guide to Climatological Practices, provided for the summaries to be computed by method (a) also and it was found that there were sometimes appreciable differences between values computed by the two methods when there were missing observations (at high levels). To provide data upon which to base a decision as to the method to be used for future routine work further modifications were made to the programme so that, after the normal monthly summary had been produced, the data already in the computer could be used to compute vector mean winds by each of the methods (a), (b), (c), using distributions obtained by omitting a random selection of data from originally complete distributions at the lower levels, for which the true values were known.

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/RANDOM SELECTION PROCEDURE.

RANDOM SELECTION PROCEDURE.

The procedure adopted was as follows. Only data for the first ten levels (surface to 250 mb) of an ascent were used in the tests; this virtually ensured that the original data were complete as there are seldom any missing values below 200 mb. The computer was instructed to make first a random selection of dates for which data were to be regarded as missing at all hours of observation. These missing dates were selected by making ten "picks" from numbers between 0 and 60; this provided for some variation in the different series of tests as the number of missing days could lie between 0 and 10. Having picked missing dates the computer was next instructed to pick missing individual values either in one stage or in two stages as follows:- Numbers 0, 1, 2 . . . . 9 referred to data for the surface, 900, 850 . . . 250 mb at 00 G.M.T., numbers 10, 11, 12 .... 19 referred to data for those levels at 06 G.M.T. and so on. For a first stage selection the computer was instructed to make, for each day of the month, four random picks from numbers between 0 and 63 and to omit data for the hour and level corresponding to the selected number. If a number between 40 and 63 was picked no data were omitted; this procedure had some technical advantages and also introduced a further random element into the selection of missing data by not automatically omitting four values each day.

Incomplete distributions resulting from the omission of values selected as described above had roughly the same numer of observations at each hour and were used for what are referred to later in this note as series A tests.

For a second stage selection of missing values the computer, after making s selection of missing values from all four hours of observation as described for stage one, was instructed to make ten more picks from numbers in the ranges 10-19 and 30-39, i.e. of values for two of the hours of observation only.

Incomplete distribution produced in this way had considerably fewer observations at 06 and 18 G.M.T. than at 00 and 12 G.M.T.; they were used for what are later described as series B tests. For these tests with a station making ascents only at 00 and 12 G.M.T. the instructions were modified so that these second stage missing data were picked from 12 G.M.T. data only.

When carrying out a set of tests the same selection of missing dates was usually used for several successive tests as, owing to the arrangement of the programme, the selection of new dates involved first recomputing and reprinting the "complete" summaries for the combined hours.

COMPUTATIONS.

After making the required selection of numbers the computer omitted values corresponding to these numbers and computed by each method, using combined hours data for each of the ten levels in turn, the vector mean wind and average wind speed and the vector difference between the vector mean winds for complete and incomplete distributions; the standard vector deviation of the incomplete distribution was also computed and particulars given of the numbers of observations used. For computing the standard vector deviation, components computed by method (a) and mean sums of squares computed in an analogous manner were used.

The results obtained have been used for this note though for this purpose a carefully planned series of statistical tests would have been better; a decision as to which method should be used was urgently required, however, and the modifications made to the existing programme were of a rather impromptu nature designed only to give comparative results for the three methods.

Table I shows the results of a set of series B tests (fewer data at two of the hours of observation) using data for Aldergrove for March 1959;

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these have been selected as being fairly representative of the general run of results but there were large variations in the vector error at the higher levels in the different tests.

The upper part of the table gives the missing data numbers and the lower part the values computed from the resulting incomplete distributions. Most of the table is as printed by the computer but some explanatory headings have been added.

SUMMARIES OF RESULTS OF TESTS

(1) Tests using data for Lerwick for March 1959.

Ten sets of tests were carried out using these data. One selection of missing days (i.e. all observations missing) was used for the first five sets of tests and another for the second five sets of tests. The actual number of missing days was six for the first five tests and five for the remainder. For the first and sixth sets of tests the missing values were selected from any of the four hours of observations (series A tests); for the other tests a selection of missing values from any of the four hours of observation was followed by a further selection of missing values taken from data for 06 and 18 G.M.T. only (series B tests). A good indication of the number of observations used in the different tests is given by the following figures for the number of observations at the different hours in the first and second tests:-

Level	First test 00	06	12	18 G.M.T.	Second test 00	06	12	18 G.M.T.
Surf.	25	25	24	22	24	20	22	19
900 mb	25	22	25	23	24	19	25	19
850 "	23	23	23	24	22	18	23	19
800 "	23	23	24	25	23	15	24	21
700 "	24	25	23	23	24	18	22	19
600 "	24	25	23	24	25	16	23	21
500 "	23	22	24	24	25	13	23	15
400 "	23	25	24	23	25	18	24	17
300 "	24	22	24	25	25	16	24	17
250 "	22	23	23	25	25	12	22	18

A summary of the results obtained is given in Table 2.

It should be noted that although data for the surface, 900, 850 mb. etc. have been used for the tests and are referred to in the tables by the level used to provide the data, they are meant to be regarded as slightly different distributions used for separate tests of the effect of missing observations; the results are not meant to show what would be the relative effect of the loss of observations at the surface, 900 mb. etc.

The analysis of results in Table 2 shows that, in general, for distributions of this type, the use of method (a) gives better estimates of true values than method (b) as regards all three criteria used for comparison - total of mean errors for different tests, maximum error in any test and the number of occasions when errors were smaller by method (a) than by method (b), the differences being most marked for the series B tests.

It is interesting to note from the summaries at the foot of the table that in the series A test the use of method (c) gave slightly worse estimates of the true values than method (b) but in the series B tests method (c) gave appreciably better results than method (b).

Other points of interest are discussed later.

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(2) TESTS USING DATA FOR ALDERGROVE AND O.W.S. JULIETT.

Further tests were carried out using winds for Aldergrove and for O.W.S. Juliett for March 1959. For the Aldergrove tests three different selections of missing days were used, the number of missing days being four then two then four. With each selection of missing days one series A and two series B selections of individual missing data were made and tests carried out. For the O.W.S. Juliett tests only one selection of missing days was made giving two missing days; one series A and two series B tests were then carried out. The results are summarised (in less detail than for Lerwick) in Table 3.

The results confirm the conclusions based on the tests using values for Lerwick; method (a) again gives, in general, the best estimates of the true values, the departures being most marked for the series B tests.

The summaries at the foot of the table show that in the series A tests there is little to choose between estimates of the true values obtained by methods (b) and (c) but in the series B tests method (c) gives, on the whole, definitely better estimates.

(3) TESTS USING DATA FOR ADEN FOR MARCH 1959.

The wind distributions used in the previous tests were typical of winds prevailing over the British Isles for much of the year. Another series of tests was carried out using winds for Aden to see how results by each method compared when used with a distribution in which there was a considerable variation of wind direction with height, a type often experienced in the British Isles in summer.

For these tests data for two hours of observation a day only were available. Five sets of test were carried out omitting data selected at random from either hour (series A tests) and then a further five sets of tests omitting data from the 12 G.M.T. observations only (series B tests). For each of the five sets of tests a random pick of "missing days" was made first and gave two missing dates for each set of tests. The resulting number of observations is shown below:-

Level	Five series A tests										Five series B tests									
	G.M.T.										G.M.T.									
	00	12	00	12	00	12	00	12	00	12	00	12	00	12	00	12	00	12	00	12
Surf.	29	28	26	24	23	23	25	24	26	27	29	9	25	10	26	14	28	17	27	17
900 mb	29	29	25	25	22	23	25	25	26	27	28	15	25	12	29	11	28	17	29	15
850 "	26	27	23	21	21	23	23	23	26	28	24	14	26	11	27	19	26	11	27	18
800 "	26	28	23	26	23	23	23	24	28	26	25	14	28	16	29	16	27	16	27	16
700 "	28	27	25	24	22	21	24	23	27	28	29	15	29	19	24	12	27	9	28	14
600 "	28	27	25	24	23	22	24	23	28	25	29	14	28	9	29	14	28	9	29	14
500 "	27	28	24	24	22	22	23	24	26	28	26	15	29	11	27	14	28	18	26	19
400 "	26	28	25	24	24	21	23	24	27	27	28	12	27	19	27	14	26	18	29	14
300 "	28	28	24	26	24	22	24	24	27	28	28	17	27	16	25	15	28	18	27	17
250 "	26	26	25	25	21	22	22	23	29	27	27	8	28	11	28	17	28	13	25	15

Summarised results of the tests are given in Table 4. In this table as the number of series A and series B tests were the same, total vector errors have been given in preference to mean values.

A study of the results shows that as regards series A tests there is little to choose between the methods though, in general, method (a) was rather better; method (a) gave a slightly lower figure for the total vector error for all tests and also gave a better estimate of the true value more often than method (b) but it gave the greatest maximum error.

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The results of the series B tests fall into two categories. For the surface and 900 mb. levels, estimates by method (a) are definitely worse than those by method (b) and an examination of daily values showed that there was usually a marked diurnal variation of wind at these levels. At the higher levels method (a) gave, on the whole, better estimates though for the transition levels of wind from easterly to westerly between 700 and 500 mb, method (b) gave better results.

For both series of tests the results using method (c) are very similar to those obtained by method (a).

These two sets of tests show that for distribution of this type the use of method (a) will probably give better results in general: the poor results obtained by method (a) when using data for the surface and 900 mb can be largely discounted as regards its use for wind summaries at high levels (where any missing observations normally occur) as the diurnal variation shown by winds at low levels is unlikely at high levels. The results do show however, that method (a) should not be used for an element having a pronounced diurnal variation.

(4) Further discussion of results. In addition to providing an answer to the primary question as to which is the best method to use for routine summaries the tables provide partial answers to associated questions which are of interest.

One of these is the practical question; is the use of method (a), which entails far more effort than method (b) - particularly if values for different hours have been entered on separate sheets - really necessary if the computing has to be done by hand? Values in the tables suggest that provided there are about the same number of observations at each hour the use of method (a) to obtain a slightly better estimate of the true values is not really necessary. If the number of observations is decidedly different the appreciably greater errors shown in Table 3, when using method (b) for the series B tests for Aldergrove and O.W.S. Juliett, suggest that the use of method (a) may be desirable.

Another question is, how do estimates of the standard vector deviation of the complete distribution obtained from the incomplete distribution compare with the true values? Maximum errors in the estimates of the standard vector deviation in the different tests for each station, expressed as percentages of the true standard vector deviation, are given in Table 5.

The values show that apart from one outstanding error of 15% the errors are not usually greater than about 5% of the true standard vector deviation. Even for the surface and 900 mb. distributions at Aden where the errors in the estimate of the vector mean wind by method (a) are large (see Table 4) the errors in the estimated standard vector deviation (which was computed following method (a) procedure) are less than 10%. It seems therefore that if the standard vector deviation of the incomplete distribution is taken as being an approximation to the true value the error will only occasionally be more than 10% and will often be not more than 5%.

A further practical question is, what sort of errors are likely to arise in the estimate of a vector mean wind using an incomplete distribution and can they be related to the standard vector deviation? Maximum vector errors found in the tests are given in Tables 2 - 4 and, as might be expected, the largest numerical errors occur with the largest standard vector deviations. Table 6 shows these errors expressed as percentages of the standard vector deviations. They were computed using the standard vector deviation of the appropriate incomplete distribution but to condense the table the standard vector deviations

/ shown for

shown for each station are those for the complete distributions. No values have been given for the errors at the surface and 900 mb. levels for Aden when using method (a) in the series B tests as this method should not be used to compute a mean value for data showing a pronounced diurnal variation.

The values in Table 6 suggest that a rough answer to the question is that maximum errors of from 10 - 20% of the standard vector deviation of the incomplete distribution may be expected. If the distribution can be regarded as being very similar to one of the test distributions (as specified by the parameters in Tables 2 - 4 and the number of observations at different hours on pp. 3 and 4) a somewhat more precise answer can be given. For distributions of the Lerwick or Aldergrove type, maximum errors are likely to be 10 - 15% of the standard vector deviation if the numbers of observations at different hours are unequal but only 5-10% if the numbers are about the same; for the Aden type of distribution, which shows a considerable variation of wind with height, maximum erros of 15 - 20% are often likely.

5. Conclusions. For routine summaries of upper winds produced by an electronic computer, where the arithmetic involved is a minor consideration and unique instructions are required, the use of method (a) for the computation of combined hours summaries of wind is recommended. If arithmetic is a consideration the use of method (b) can be regarded as satisfactory when there are roughly the same number of observations at each hour.

For summaries of an element for which the diurnal variation is greater than the interdiurnal variation, method (b) should be used.

Rough estimates of the maximum vector error of a vector mean wind computed from an incomplete distribution can be made from the standard vector deviation.

6. Acknowledgment. I am indebted to Mr. P.B. Sarson for help with the random selection procedure and to Mr. F.E. Lumb for some very helpful criticism of the draft of this note.

REFERENCES.

1. Geneva, World Meteorological Organisation; Guide to Climatological Practices, Geneva 1960, WMO - No. 100 TP. 44, para. 11.4.

TABLE I. Results of a set of series B tests using Aldergrove upper winds for March 1959.

MISSING DATA

1	ALL DATA				32	11	33	38	39	10					
2	39				12	17	30	31	35						
3	6				13	34	13	33	12	37					
4	1	39	22		33	38	17	36	38	15	38	31			
5	24	11	34	19	30	12	36	18	34	19	11				
6	1				35	39	16	17	17						
7	36	11	21		36	14	12	30	30						
8	36	38	35		39	15	13	34	10						
9	27	7			15	18	10	38	16	37	32				
10	39	23	24	19	30	10	38	19							
11	0	32	34	9	39	11	38	30	34	19					
12	30				11	32	10	32	16	33	34	11			
13	8	35			31	13	17	19	17	30					
14	13	7			17	15	31	35	15	18	15	38			
15	10	27	25		35	36	17	35	35	14					
16	25	37			13	19	11	38	30	14					
17	24	34			11	13	10	19	34	35	12				
18	31	30			16	35	37	36	39	30					
19	38	11	15		32	35	12	14	14	36	39				
20	9	20	29		34	31	15	12	17	17	16	13			
21	ALL DATA				11	11	13	38	30						
22	36	23	29	31	39	18	31	15	12	30	39	31			
23	21	1	6		15	33	14	33	19	19	17	31			
24	17	10			39	37	31	16	17	14					
25	0				34	12	35	31	19	16	39				
26	13	0	17		36	31	37	31	18	39					
27					11	12	31	38	30	34					
28	29				14	10	30	37	19	30	30				
29	25	27	6	5	11	37	35	39	35	16					
30	9	9													
31	11	29	2	36											

ALDERGROVE
MARCH 1959

UPPER WINDS - MONTHLY SUMMARY - COMBINED HOURS.

Test No.	Method (a) Vector mean wind °	kt.	SVD kt.	Vector error kt.	Av. speed kt.	Days with obs.	Method (b) Vector mean wind °	kt.	Vector error kt.	Av. speed kt.	No. of obs. 00h	06h	12h	18h	Method (c) Vector mean wind °	kt.	Vector error kt.	Av. speed kt.	Total obs.
0	152	7.6	9.7	0.5	10.8	29	154	7.6	0.8	11.0	26	20	28	16	154	7.5	0.7	10.9	90
1	183	14.8	20.9	0.8	23.5	29	181	14.7	1.2	23.3	26	17	27	17	183	14.5	0.8	23.2	87
2	197	13.8	20.4	0.8	22.9	29	201	13.2	2.0	22.6	28	19	28	24	200	13.3	1.7	22.7	99
3	200	14.0	19.9	0.5	22.5	29	202	13.6	1.1	22.5	29	21	27	24	201	13.5	1.0	22.5	101
4	204	14.4	22.0	0.4	24.2	29	208	14.6	1.1	25.0	29	22	26	17	207	14.6	0.9	25.0	94
5	207	14.9	25.3	1.2	26.6	29	209	15.0	1.2	25.9	28	21	26	18	208	14.8	1.0	25.9	93
6	214	13.0	31.1	0.3	30.5	29	214	13.8	0.7	30.5	26	21	29	19	212	13.8	0.8	30.5	95
7	223	13.5	37.2	0.3	35.3	29	216	12.3	2.7	33.8	27	19	26	21	216	12.5	2.0	34.0	93
8	239	12.9	43.3	0.7	39.9	29	247	12.7	1.7	40.0	28	24	29	18	243	12.5	1.3	39.8	99
9	261	15.3	40.8	3.4	37.6	29	263	15.4	3.9	38.2	26	18	25	16	261	15.3	3.4	37.9	85

TABLE 2. RESULTS USING UPPER WINDS FOR LERWICK, MARCH, 1959.

Level	Complete data			Two series A tests										Eight series B tests									
	Vector mean wind		S.V.D.	Mean vector error (kt) Method			Max. vector error (kt) Method			Occasions when vector error of (a) cf (c)				Mean vector error (kt) Method			Max. vector error (kt) Method			Occasions when vector error of (a) cf (c)			
				(a)	(b)	(c)	(a)	(b)	(c)	<(b)	>(b)	<(b)	>(b)	(a)	(b)	(c)	(a)	(b)	(c)	<(b)	>(b)	<(b)	>(b)
	o	kt	kt																				
Surf.	183	11.6	14.7	1.2	1.1	1.2	1.4	1.2	1.3	0	1	0	2	1.1	1.2	1.2	1.4	1.9	1.6	4	3	1	4
900 mb	191	16.4	19.7	0.9	1.1	1.1	1.1	1.3	1.3	1	0	0	0	1.2	1.3	1.3	2.0	2.1	2.0	4	2	3	4
850 "	198	16.5	19.5	1.1	1.1	1.1	1.1	1.6	1.5	1	1	0	0	0.9	1.1	1.1	1.7	2.3	2.0	4	4	4	2
800 "	203	16.5	19.3	0.7	0.9	0.9	1.3	1.4	1.4	2	0	0	0	1.1	1.6	1.4	1.7	2.8	2.6	7	1	8	0
700 "	208	16.9	20.3	0.7	1.0	1.1	1.1	1.7	1.7	1	1	0	1	1.1	1.3	1.2	2.2	2.5	2.3	5	3	6	2
600 "	212	16.8	23.4	0.9	1.1	1.1	1.5	1.4	1.4	1	1	0	0	0.9	1.3	1.2	1.9	2.1	1.9	5	2	5	2
500 "	218	17.3	27.7	1.1	1.0	1.1	1.6	1.4	1.5	1	1	0	1	1.2	1.3	1.2	2.5	2.1	2.0	4	4	4	2
400 "	225	18.3	36.2	1.3	1.2	1.2	2.0	1.8	1.8	0	2	0	0	1.7	2.1	1.7	2.7	4.4	3.0	4	3	6	1
300 "	233	19.5	43.5	2.3	2.8	2.8	2.5	3.3	3.3	2	0	0	0	2.1	3.1	2.8	3.4	6.4	5.3	4	4	6	2
250 "	214	20.4	40.0	2.2	2.3	2.3	2.2	2.3	2.4	2	0	0	1	2.6	4.0	3.6	3.4	5.1	4.3	7	1	6	1
Total				12.4	13.6	13.9				11	7	0	5	13.9	18.3	16.7				48	27	49	20
Max.							2.5	3.3	3.3								4.6	6.4	5.3				

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TABLE 3. RESULTS USING UPPER WINDS FOR (1) ALDERGROVE (2) O.W.S. JULIETT for MARCH, 1959.

(1) Aldergrove

(2) O.W.S. Juliett

Level	Complete data			Three series A tests						Six series B tests						Complete data			One series A test			Two series B tests					
	Vector S.V.D.			Mean vector error (kt) Method			Max.vector error (kt) Method			Mean vector error (kt) Method			Max.vector error (kt) Method			Vector S.V.D.			Vector error (kt) Method			Mean vector error (kt) Method			Max. vector error (kt) Method		
	mean wind o	kt	kt	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	mean wind o	kt	kt	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)
Surf.	149	7.3	9.4	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.7	0.6	0.7	1.3	1.1	219	8.6	24.7	1.7	2.6	2.6	1.9	2.1	1.9	2.0	2.4	2.2
900 mb	186	14.3	20.4	0.8	0.9	0.9	1.1	1.3	1.3	1.1	1.1	1.0	2.7	2.5	2.4	214	12.3	29.9	1.8	2.5	2.5	2.7	2.7	2.9	2.8	3.5	3.5
850 "	195	14.5	20.0	0.7	0.7	0.7	1.5	0.9	0.9	0.9	1.5	1.3	1.3	2.3	2.0	214	13.2	29.0	3.4	4.5	4.4	1.9	3.2	3.4	2.1	4.3	4.2
800 "	199	14.4	19.5	0.8	1.0	0.9	1.3	1.4	1.4	0.7	1.3	1.1	1.1	1.9	1.7	216	14.9	28.8	2.4	4.1	4.1	2.3	4.5	4.5	2.7	4.8	4.8
700 "	204	14.0	21.5	0.9	1.2	1.2	1.5	1.4	1.4	1.0	1.6	1.5	1.9	3.1	3.1	220	18.2	30.3	1.8	3.7	3.7	2.1	3.7	3.9	2.6	4.3	4.3
600 "	208	13.8	24.8	1.3	1.5	1.5	2.1	2.3	2.3	1.3	1.5	1.5	2.1	2.6	2.4	218	21.6	31.3	1.7	3.6	3.6	1.9	3.8	3.8	2.3	4.2	4.2
500 "	214	13.1	29.9	1.4	1.3	1.3	2.0	1.9	2.0	1.3	1.9	1.7	2.0	3.1	3.0	221	24.0	34.2	2.0	5.0	5.0	2.2	6.1	5.6	2.4	6.2	5.8
400 "	224	13.4	37.4	1.4	1.4	1.4	2.3	2.3	2.3	1.7	1.9	2.0	4.3	2.8	3.0	220	26.6	43.2	3.8	4.7	4.6	4.7	7.3	6.5	5.1	8.3	7.2
300 "	240	13.5	43.5	1.9	1.9	1.9	3.6	4.0	3.9	1.5	2.8	2.5	3.4	5.6	5.2	232	28.6	51.6	5.3	5.7	5.7	5.2	6.1	6.1	5.8	6.2	6.1
250 "	249	15.8	39.2	1.3	2.2	2.2	2.1	2.8	2.8	1.8	2.7	2.3	3.4	4.4	4.1	235	28.0	49.6	5.3	6.5	6.3	5.9	7.2	7.6	6.4	9.0	9.3
Total				10.7	12.4	12.3				11.8	17.0	15.5							29.2	42.9	42.5	30.8	46.7	46.2			
Max.							3.6	4.0	3.9				4.3	5.6	5.2				5.3	6.5	6.3				6.4	9.0	9.3

TABLE 4. RESULTS USING UPPER WINDS FOR ADEN FOR MARCH 1959.

Level	Complete data			Five series A tests										Five series B tests									
	Vector mean wind		S.V.D.	Total vector error (kt) Method			Max. vector error (kt) Method			Occasions when vector error of (a) < (b)	of (a) > (b)	of (c) < (b)	of (c) > (b)	Total vector error (kt) Method			Max. vector error (kt) Method			Occasions when vector error of (a) < (b)	of (a) > (b)	of (c) < (b)	of (c) > (b)
				(a)	(b)	(c)	(a)	(b)	(c)					(a)	(b)	(c)	(a)	(b)	(c)				
	o	kt	kt																				
Surf.	98	11.8	6.4	0.9	1.1	1.0	0.3	0.3	0.3	2	1	2	1	9.0	1.6	6.2	2.2	0.7	1.7	0	5	0	5
900mb	84	9.8	7.7	2.7	3.0	3.0	1.3	1.5	1.5	2	0	0	0	4.9	3.0	3.1	1.4	0.9	1.0	0	4	1	3
850"	81	6.5	9.5	4.4	3.2	3.2	1.3	0.9	1.0	0	4	1	1	2.0	4.1	3.0	1.0	1.6	1.0	3	0	3	0
800"	94	4.2	10.1	2.9	4.6	4.6	1.6	2.0	2.0	5	0	0	0	3.8	5.3	5.1	1.4	1.8	1.6	4	1	3	2
700"	68	6.6	11.0	2.7	2.6	2.8	0.6	0.8	0.8	1	2	0	2	7.0	5.5	7.1	1.9	1.7	2.0	2	3	1	4
600"	78	3.1	9.4	2.8	3.0	3.0	1.0	1.0	1.0	3	2	0	0	5.2	4.1	5.2	1.6	1.6	1.3	1	3	1	4
500"	190	5.1	11.6	3.6	4.2	4.0	1.2	1.8	1.8	3	1	2	0	4.7	4.2	4.8	1.4	1.0	1.5	2	3	2	3
400"	223	8.9	12.0	3.4	3.4	3.3	0.9	1.1	1.0	2	2	1	0	4.3	6.9	6.3	1.4	2.0	1.8	4	1	4	0
300"	242	11.7	14.8	2.9	2.2	2.3	1.0	0.9	0.9	1	4	0	1	4.5	5.1	4.6	1.9	1.8	1.4	2	2	2	2
250"	243	13.0	18.4	6.4	6.2	6.2	2.4	1.8	1.8	3	2	0	0	7.5	9.8	8.1	2.0	3.5	2.3	3	1	3	1
Total				32.7	33.5	33.4				22	18	6	5	52.9	49.6	53.5				21	23	20	23
Total	omitting surface and 900 mb			29.1	29.4	29.4				18	17	4	4	39.0	45.0	44.2				21	14	19	15
Max.							2.4	2.0	2.0								2.2	3.5	2.3				

TABLE 5. MAXIMUM ERRORS OF ESTIMATES OF STANDARD VECTOR DEVIATION FROM INCOMPLETE DATA EXPRESSED AS PERCENTAGE OF TRUE VALUE.

Station	LERWICK			ALDERGROVE			O.W.S. JULIETT			ADEN		
Type of Test		A	B		A	B		A	B		A	B
Number of Tests		2	8		3	6		1	2		5	5
Level	True S.V.D.	Max. error	Max. error	True S.V.D.	Max. error.	Max. error	True S.V.D.	Max. error	Max. error	True S.V.D.	Max. error	Max. error
	kt	%	%	kt	%	%	kt	%	%	kt	%	%
Surf.	14.7	3	8	9.4	3	4	24.7	0	2	6.4	6	6
900 mb	19.7	5	4	20.4	2	3	29.9	3	5	7.7	4	9
850 "	19.5	4	5	20.0	3	3	29.0	10	2	9.5	8	15
800 "	19.3	4	6	19.5	4	4	28.8	3	6	10.1	7	7
700 "	20.3	6	8	21.5	4	5	30.3	1	2	11.0	5	5
600 "	23.4	4	6	24.8	5	6	31.3	2	4	9.4	6	4
500 "	27.7	4	4	29.9	8	7	34.2	1	1	11.6	5	3
400 "	36.2	4	7	37.4	5	7	43.2	6	6	12.0	3	6
300 "	43.5	1	5	43.5	5	5	51.6	6	7	14.8	10	4
250 "	40.0	3	5	39.2	3	4	49.6	5	9	18.4	9	7

TABLE 6. MAXIMUM ERRORS OF ESTIMATE OF VECTOR MEAN WIND EXPRESSED AS PERCENTAGE OF STANDARD VECTOR DEVIATION COMPUTED FROM INCOMPLETE DATA.

Station	LERWICK					ALDERGROVE					O.W.S. JULIETT					ADEN				
Type of Test		A		B			A		B			A		B			A		B	
No. of tests		2		8			3		6			1		2			5		5	
Method		(a)	(b)	(a)	(b)		(a)	(b)	(a)	(b)		(a)	(b)	(a)	(b)		(a)	(b)	(a)	(b)
Level	S.V.D. *	Max. error				S.V.D. *	Max. error				S.V.D. *	Max. error				S.V.D. *	Max. error			
	kt	%	%	%	%	kt	%	%	%	%	kt	%	%	%	%	kt	%	%	%	%
Surf.	14.7	9	8	9	13	9.4	3	4	7	14	24.7	7	11	8	10	6.4	5	5	-	11
900 mb	19.7	5	6	10	10	20.4	5	6	13	12	29.9	6	9	9	12	7.7	18	20	-	12
850 "	19.5	8	7	8	11	20.0	7	4	7	11	29.0	13	17	7	15	9.5	15	10	9	15
800 "	19.3	6	7	9	14	19.5	7	7	6	10	28.8	9	15	10	18	10.1	16	20	14	18
700 "	20.3	5	8	11	12	21.5	7	7	9	15	30.3	6	12	9	15	11.0	5	7	17	15
600 "	23.4	6	6	8	8	24.8	9	10	9	10	31.3	6	12	8	14	9.4	11	11	17	17
500	27.7	6	5	9	7	29.9	7	6	7	11	34.2	6	15	7	18	11.6	11	16	12	9
400 "	36.2	5	5	7	12	37.4	6	6	11	7	43.2	9	12	13	20	12.0	8	9	11	17
300 "	43.5	6	8	8	15	43.5	8	9	8	13	51.6	11	12	12	13	14.8	6	6	12	13
250 "	40.0	6	6	8	12	39.2	5	7	8	11	49.6	11	14	14	20	18.4	12	9	10	18

* Values for complete distribution.

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